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Computer-Based Land Classification for Management of Hazardous Waste

Corvallis Environmental Research Lab., OR

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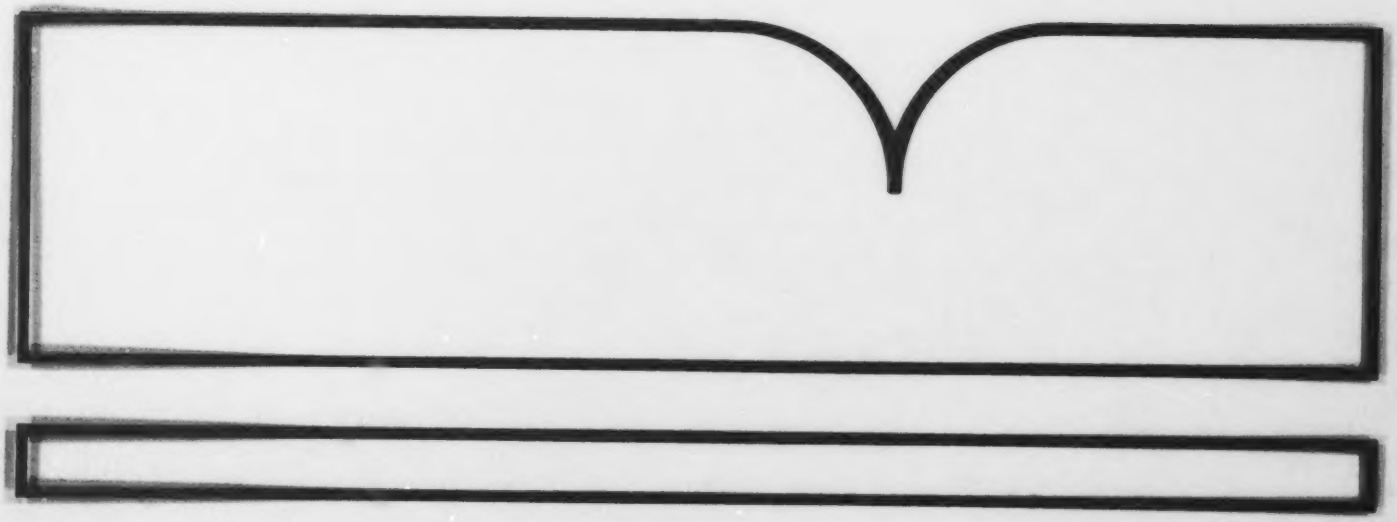

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16. ABSTRACT

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The mapping is a part of the EPA Corvallis Environmental Research Laboratory's Assessment Program. This program examines the bioavailability of complex chemicals from hazardous waste sites using laboratory bioassays. Since bioavailability can be influenced directly by the soil environment within the context of regional biology, geology, and climate, the ecological maps described in this paper can be useful in defining hazardous waste bioavailabilty potentials on a regional basis.

The low resolution maps are useful in research and environmental management. In research they help organize existing and newly generated data so they can be better understood relative to environmental variability. In management they help to assess the feasibility of applying uniform management approaches to broad areas.

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Computer-Based Land Classification for Management of Hazardous Waste

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The classification of land based on regional attributes of climate, geology and biota is facilitated by using a computer to organize and correlate existing data bases into generalized maps useful for environmental research and resource management. A procedure for producing generalized low resolution ecological maps is discussed and an outline describing the use of the maps in the management of hazardous waste is presented. While the focus of many hazardous waste studies is upon human health effects, the emphasis of this approach is on ecological effects.

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INTRODUCTION

Hazardous waste sites often release complex toxic chemicals to the environment. The release may be inadvertent as from abandoned dumpsites, impoundments, waste lagoons, exposed waste dumps, leaking containers in unprotected storage, and buried drums. The environment may be adversely impacted by these, as well as by controlled release from active sites and accidental spills.

The portion of the toxic waste that reaches groundwater becomes a major source of human health problems. The portion that surfaces downslope of the site or drains into a stream becomes a source of ecological impact problems as well.

An important ecological concern is the recognition that various environments have differing potentials for attenuation of harmful effects of toxic waste and that a realistic and effective management approach recognizes and works within the limitations of this potential. The environmental characteristics of climate, geology, and biota together predetermine this potential. If this information is organized into integrated maps, it may be helpful in understanding the influence of hazardous wastes on biota in areas with similar environmental characteristics. For example, uniform management alternatives may be planned for these environmentally homogeneous regions as a whole, and specific treatments might be envisioned for particular sites within the region. Furthermore, existing data for a site within a given region can be more effectively evaluated relative to their suitability for extrapolation to another location within that same or a similar region.

Interaction of hazardous chemicals with a soil sample may be among the most important factors in determining environmental attenuation of complex chemicals released from hazardous wastes. An analysis with this level of detailed resolution is possible once a location and the waste are identified.

There are more than 14,000 recognized soil series in the United States. Each series has a wide range of physical, chemical, and biological properties reflecting the net influence of environmental factors participating in weathering and formation of a soil. Moreover, an area known to be dominated by a single soil series may contain many patchy areas within it that represent several other soil series. Therefore, it is not practical to analyze the problem with a great deal of resolution at the outset.

Environmental characteristics useful for a low resolution analysis of many ecological problems are quantifiable over broad geographic regions using existing data. To the extent that these same characteristics also influence the local environment of a soil, we advocate dealing with the attenuation problem on a low level of spatial resolution first and progressively introducing more detailed data as the problem becomes local and the need for a greater degree of resolution becomes evident.

This paper develops a procedure for combining existing, small-scale, mapped data that define regional environmental characteristics in the U.S. into a map that can be used within the ongoing EPA program for management of hazardous waste. The integrated maps of varying degrees of resolution can delineate boundaries of ecologically uniform and distinct land types as candidates for application of uniform management approaches relative to assessment of effects, attenuation potentials, and control of hazardous waste.

In a related background study, Shirazi et al. [1] presented an example of the mapping procedure for selecting study sites from candidate abandoned hazardous waste dumpsites in the southeastern United States. He used small-scale maps of low resolution from the National Atlas [2] to delineate the boundaries and to determine the environmental characteristics that prevail over units of land within the region. A computer map-overlay and graphic approach was used to facilitate the grouping of land types. Abandoned hazardous waste dumpsites found within land types that best represent the region were surveyed for selecting study sites. Shirazi hypothesized that environmental data obtained from a representative site would be useful for predicting impact potential in similar remotely located areas within the same general region. The hypothesis is being tested in three abandoned hazardous waste sites

selected from EPA's top priority sites in the region. The ecological research is being conducted at Florida State University [3]. Again, the mapping and field studies are parts of a more comprehensive EPA program designed to further understanding of the influence of environmental variabilities on biological availability of hazardous wastes. The integrated mapping work is one way of organizing the information such that limited data sets can be applied in a more general sense.

In a second background paper Shirazi et al. [4] extended the mapping approach to cover the conterminous United States east of the Rocky Mountains. More details of the computer procedure, including digitization, editing, graphics, and integration were presented. A brief mention was made in that paper of the use of the results for hazardous waste management.

The purpose of this paper is to present a complete ecoregional map of the conterminous United States and describe how it might be used by hazardous waste decision officials. It would be useful to review our procedures and rationale for mapping so that they might be modified by others to accomplish their own objectives in resource and environmental management.

THE DATA BASE

The National Atlas of the United States [2] contains a diverse regionalized data base representing major components of the ecosystem in a geographic region. The scale of the maps is 1:7,500,000, i.e., 1 mm = 7.5 km. Thus they display only those environmental characteristics that, on the average, hold true over a whole region. Details that do not pertain to general understanding of large areas are omitted. Selected maps from the Atlas are used in an overlay procedure to classify land units representing regional characteristics.

Selection of maps must be such that components of climate, geology, and biology are represented. These are components which are essential in understanding the composition and functioning of an ecosystem. Moreover, maps supported with the most extensive data base and enjoying the most widespread use would be preferred. Consequently, we continue our earlier approach and use the following four maps: (1) the map of potential natural vegetation [5]; (2) the soils map [6]; (3) the land surface form map [7]; and (4) the surficial geology map [8].

The digitization, editing, and plotting of the maps, using a computer, is detailed in Shirazi et al. [4]. A transparent sheet of metric graph paper with 1 mm divisions was placed over each map and manual digitization of the features of each map was performed, row by row. The digitized maps agree with the originals to within 1 mm (7.5 km). The integrated areal accuracy of four overlayed maps is within 2% of the original maps but the boundaries may vary by as much as 2 mm (15 km).

(1) The map of potential natural vegetation shows the major categories of western forests, western shrub and grassland, central and eastern grassland, and eastern forests. The map has been used by Bailey [9] as a building block for understanding the overall structure and function of natural ecosystems in the United States. Its use in this paper is based on the important role that plants play in revealing the links between soil types, land form features, and climatic regions. Furthermore, the classification and the spatial distributions of animals and nonvascular plant communities are not as well known as those for vascular plants. For information related to these characteristics, Kuchler's potential natural vegetation life forms have been used [10] because they imply animals' dependence on vegetation for food and shelter, both for terrestrial and aquatic systems.

In Kuchler's map there are a total of 106 map units, each of which represents a distinct potential vegetation life form. For regrouping the life forms into a smaller number of related units, we followed the model proposed by Holdridge [see 11, p. 163] for the classification of world plant formation in terms of natural life zones, based upon climatic conditions. That model defines general classes of life zones and associated temperature and moisture values. Rather than obtaining the temperature and moisture distributions from

the climatic maps of the United States, we used generalized values from the USDA's Land Resource Regions [12]. By overlaying a similar scale map of potential natural vegetation with this map, we were able to categorize Kuchler's 106 vegetation types into 7 life zones. This regrouping is listed in Table 1.

TABLE 1
Regrouping of Kuchler's Potential Natural Vegetation into Natural Life Zones and Binary Grouping into Humid (Vh) and Dry (Vd) Forests and Grasslands (Map 1)

Vegetation Group	Life Zone	Number of Life Forms	Percent Area
1 (Vh)	Rain Forests or Wet Forests	21	11.0
2 (Vh)	Moist Forests or Grasslands	40	50.4
3 (Vd)	Dry Forests	15	8.5
4 (Vd)	Steppe	15	20.0
5 (Vd)	Thorn Steppe	7	4.1
6 (Vd)	Dry Bush	4	3.2
7 (Vd)	Desert Bush	4	2.8

(2) The soils map [6] regionalizes the United States into warm and cool soils with wet, moist, and dry zonal groups which coincide with patterns of climate and vegetation. The map units are defined by their Comprehensive Soil Classification, including order, suborder, great group, and subgroup. The classification is based on soil properties, from which soil origin can often be inferred. Soils represent an important additional component of the ecosystem. Soil texture, moisture, pH, cation exchange capacity, and organic content influence chemical migration, decomposition rates, and bioaccumulation potentials. They also help determine the presence or absence of animal and plant life. They are influenced by man, other living organisms, climate, and land form. The use of a soils map in this paper further links the various biogeoclimatic factors.

There are 330 map units, representing 330 soil subgroups. The regrouping, which was done according to zonal characteristics, is listed in Table 2.

TABLE 2
Zonal Soils of the United States and Binary Grouping into Cool (Sc) and Warm (Sw) Soils (Map 2)

Soil Group	Zonal Class	Percent Area
1 (Sw)	Warm and wet soils	7.0
2 (Sc)	Cool and wet soils	0.3
3 (Sc)	Cool and moist soils	15.6
4 (Sw)	Warm and moist soils	31.8
5 (Sw)	Warm and dry soils	45.3

(3) The land form map identifies major physical divisions, including Pacific Mountains, Intermontane, Rocky Mountains, Interior Plains, Gulf and

Atlantic Plains, and Eastern Highlands. Furthermore, it subdivides these broad regions according to the relative slope and local relief into plains, tablelands, hills, and mountains. The properties were selected to describe land surface features as they exist now, but also suggest surface variation origin [7]. Land form features are extremely important components of the ecosystem. They influence the migration of animals, propagation of plant seeds, colonization of living organisms, distribution of soil moisture, and the pattern of local temperature.

There are a total of 69 map units describing the various land surface forms. A regrouping of these into major land forms, using Hammond's upper class rungs, is displayed in Table 3.

TABLE 3
Land Surface Forms of the United States and Binary Grouping into Plains or Piedmonts (Fp) and Mountains (Fm) (Map 3)

Land Form Group	Land Form Name	Percent Area
1 (Fp)	Plains (Flat, Smooth, and Irregular)	41.5
2 (Fp)	Tablelands	12.4
3 (Fp)	Plains with Hills and and Mountains	17.4
4 (Fm)	Open Hills and Mountains	17.9
5 (Fm)	Hills and Mountains	10.9

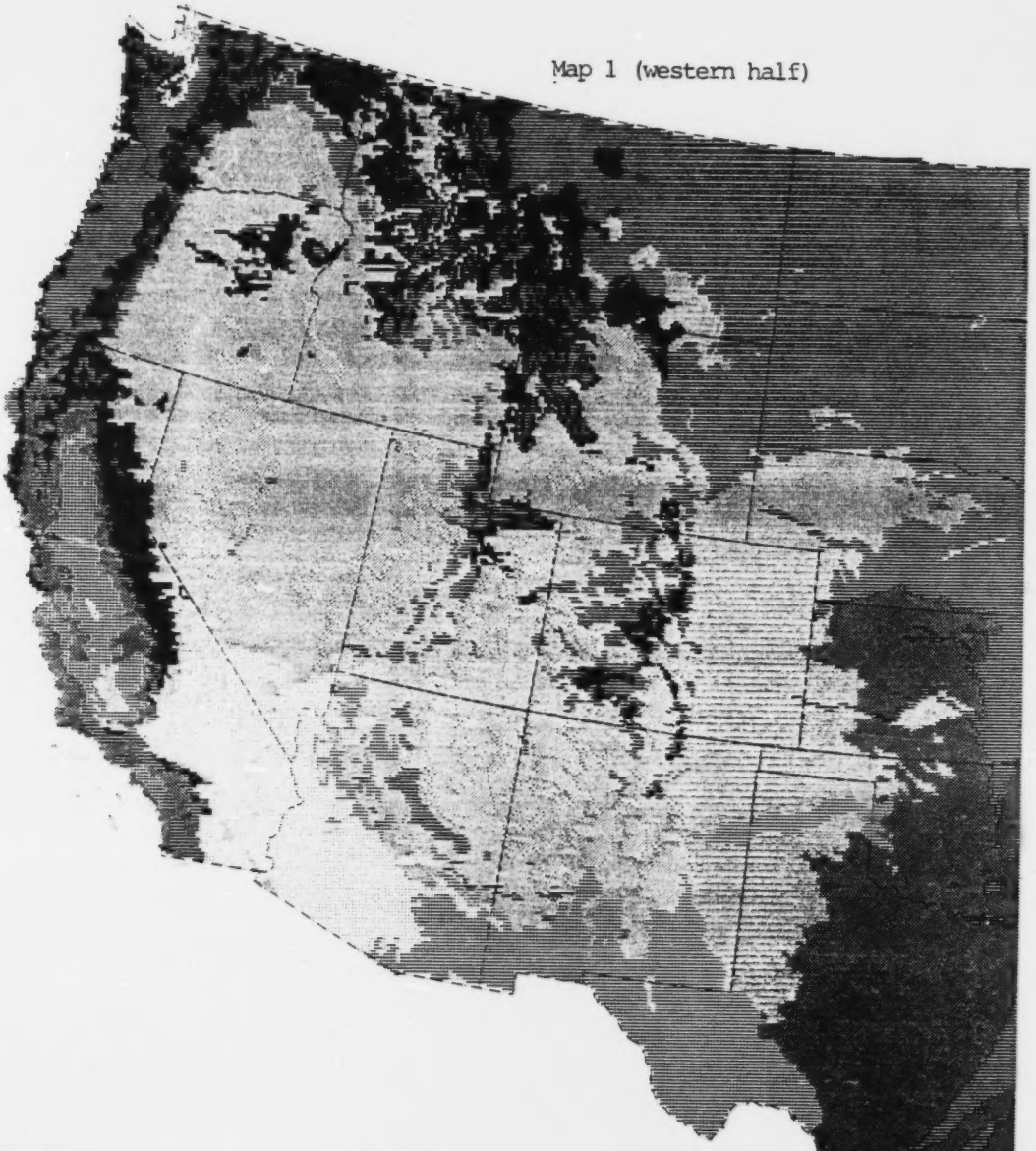
(4) The surficial geology map [8] depicts the major areas containing transported and untransported geologic materials. It further identifies origin of the transported deposits according to shore, stream, glacial, lake, and wind, as well as untransported decomposed materials in terms of thin residuum, organic, and colluvium deposits. Hunt's map [8] is an important data base regarding the overall texture, composition, and origin of surface layers of land in the United States. Like land form and soils maps, its use in this paper represents an attempt to utilize the interrelationships among ecosystem components.

There are a total of 45 map units describing modes of formation, weathering, and transport. The regrouping of these 45 surficial groups according to Hunt's classification is listed in Table 4.

TABLE 4
Surficial Geology of the United States and Binary Grouping into Locally Weathered (Gl) and Transported (Gt) Deposits (Map 4)

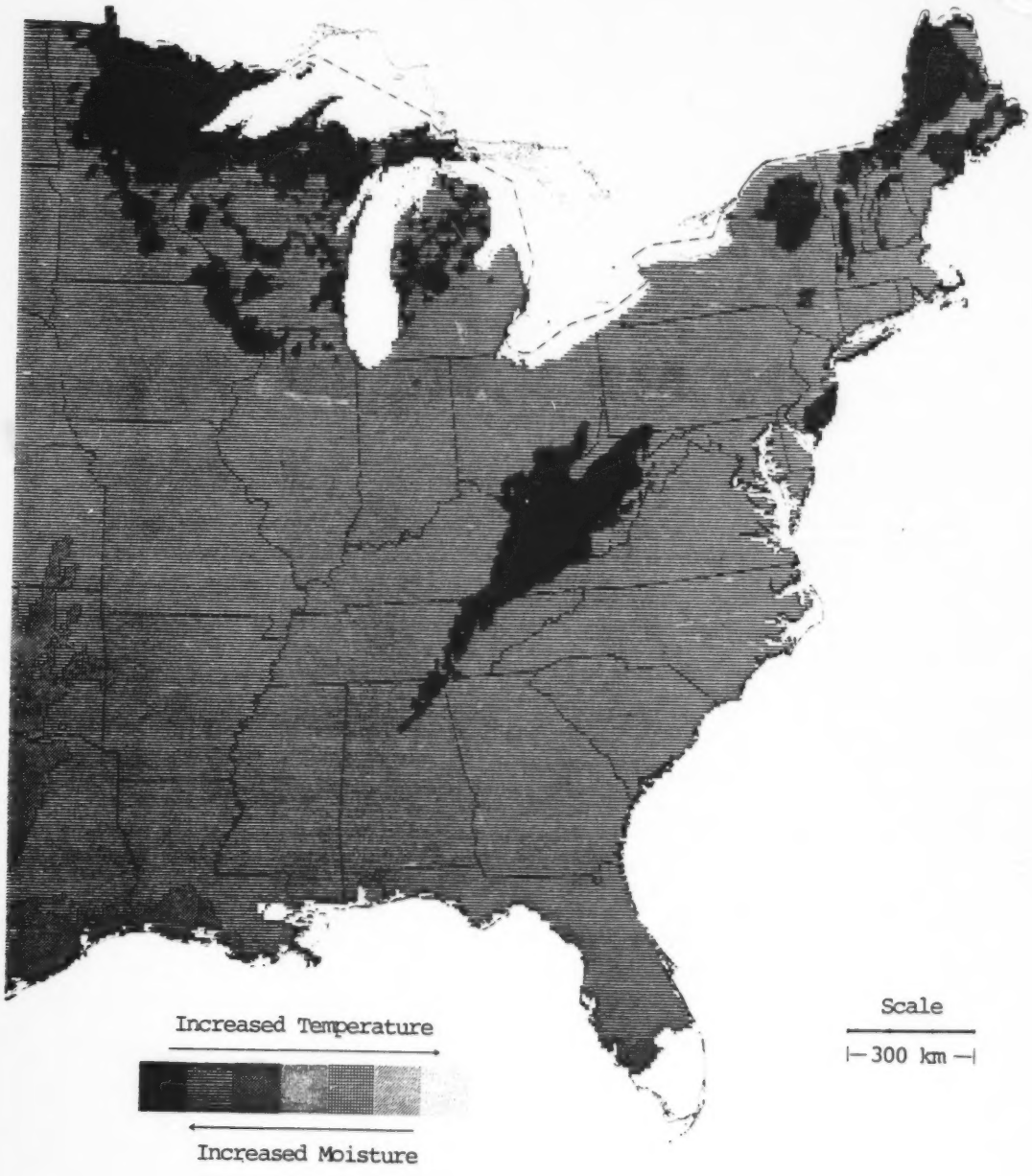
Surficial Group	Deposits	Percent Area
1 (Gl)	Organic	2.0
2 (Gl)	Sapproletic	27.1
3 (Gl)	Colluvium	21.0
4 (Gt)	Glacial	19.2
5 (Gt)	Lake and Stream	21.0
6 (Gt)	Shore	0.8
7 (Gt)	Wind	8.9

Map 1 (western half)



Vegetation Group		Life Zone	Percent Area
1	(Vh)	Rain Forests or Wet Forests	11
2	(Vh)	Moist Forests or Grasslands	50
3	(Vd)	Dry Forests	8
4	(Vd)	Steppe	20
5	(Vd)	Thorn Steppe	4
6	(Vd)	Dry Bush	3
7	(Vd)	Desert Bush	3

Map 1. Regrouping of Kuchler's Potential Natural Vegetation into Natural Life Zones and binary grouping: Humid (Vh) and dry (Vd) forests and grasslands.



Map 1 (eastern half)

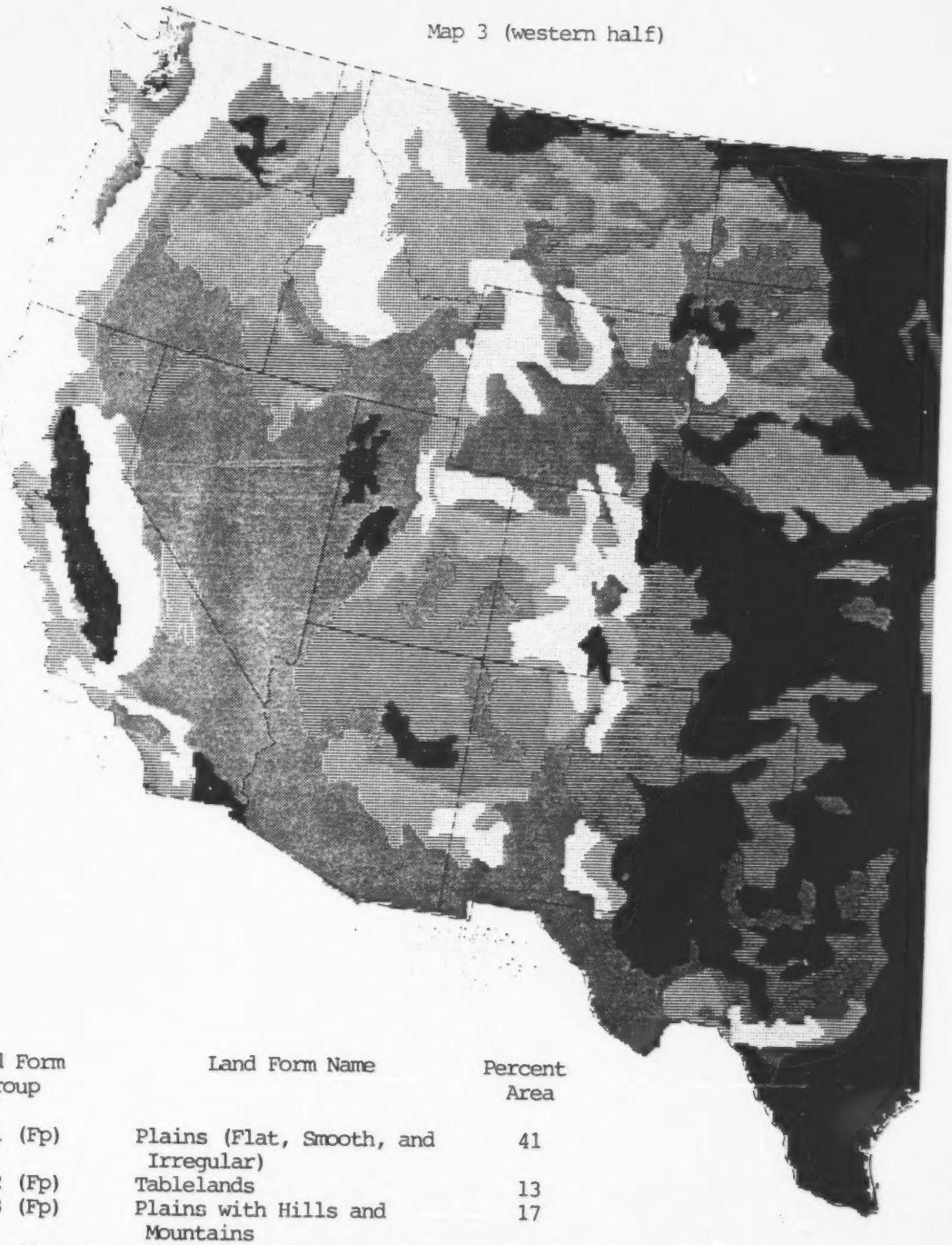
Map 2 (western half)

Soil Group	Zonal Class	Percent Area
1 (Sw)	Warm and Wet Soils	7
2 (Sc)	Cool and Wet Soils	0.3
3 (Sc)	Cool and Moist Soils	16
4 (Sw)	Warm and Moist Soils	32
5 (Sw)	Warm and Dry Soils	45

Map 2. Zonal soils of the United States and binary grouping: cool (Sc) and warm (Sw) soils.

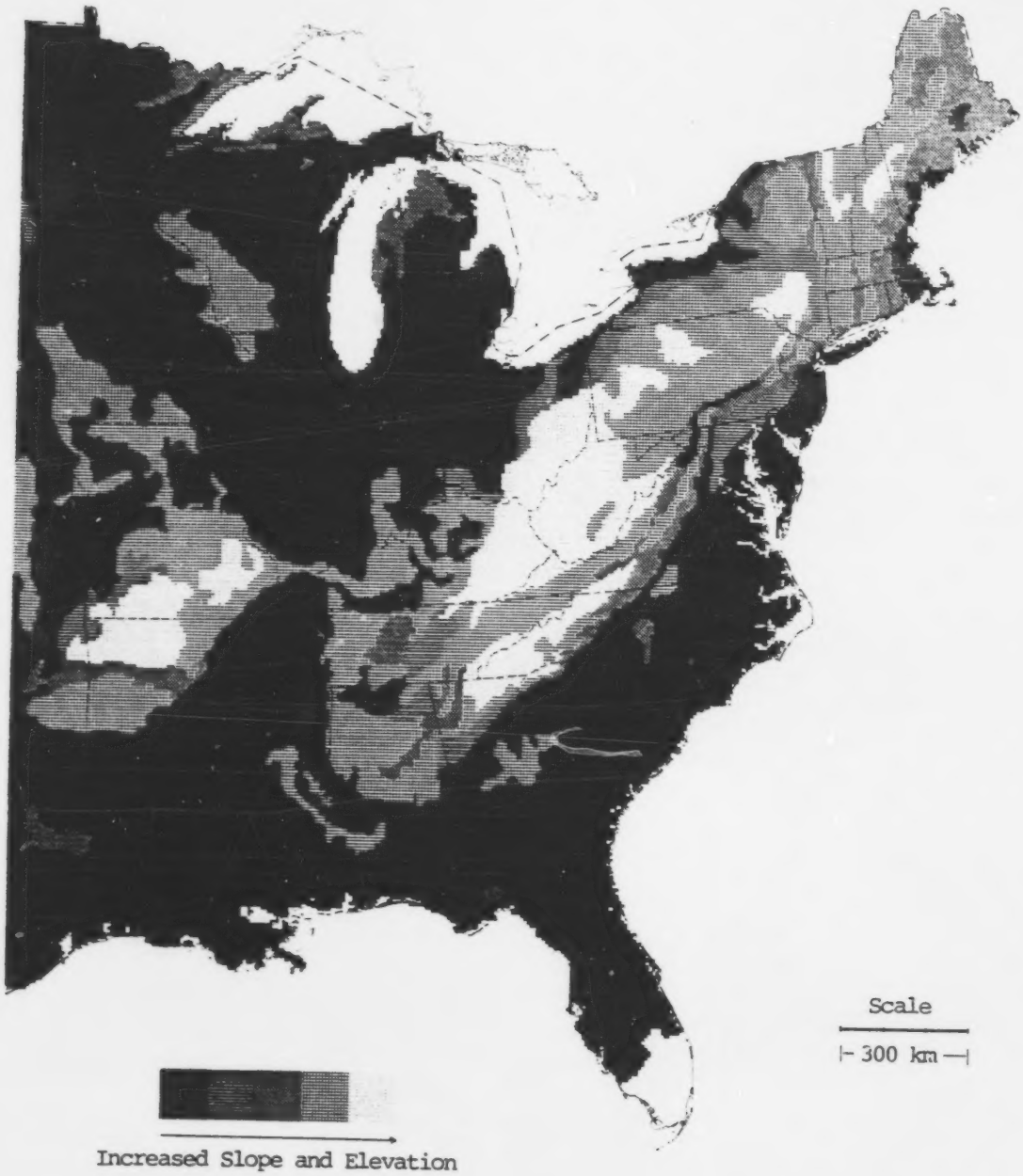
Map 2 (eastern half)

Map 3 (western half)



Land Form Group	Land Form Name	Percent Area
1 (Fp)	Plains (Flat, Smooth, and Irregular)	41
2 (Fp)	Tablelands	13
3 (Fp)	Plains with Hills and Mountains	17
4 (Fm)	Open Hills and Mountains	17
5 (Fm)	Hills and Mountains	11

Map 3. Land surface forms of the United States and binary grouping: plains or piedmonts (Fp) and mountains (Fm).

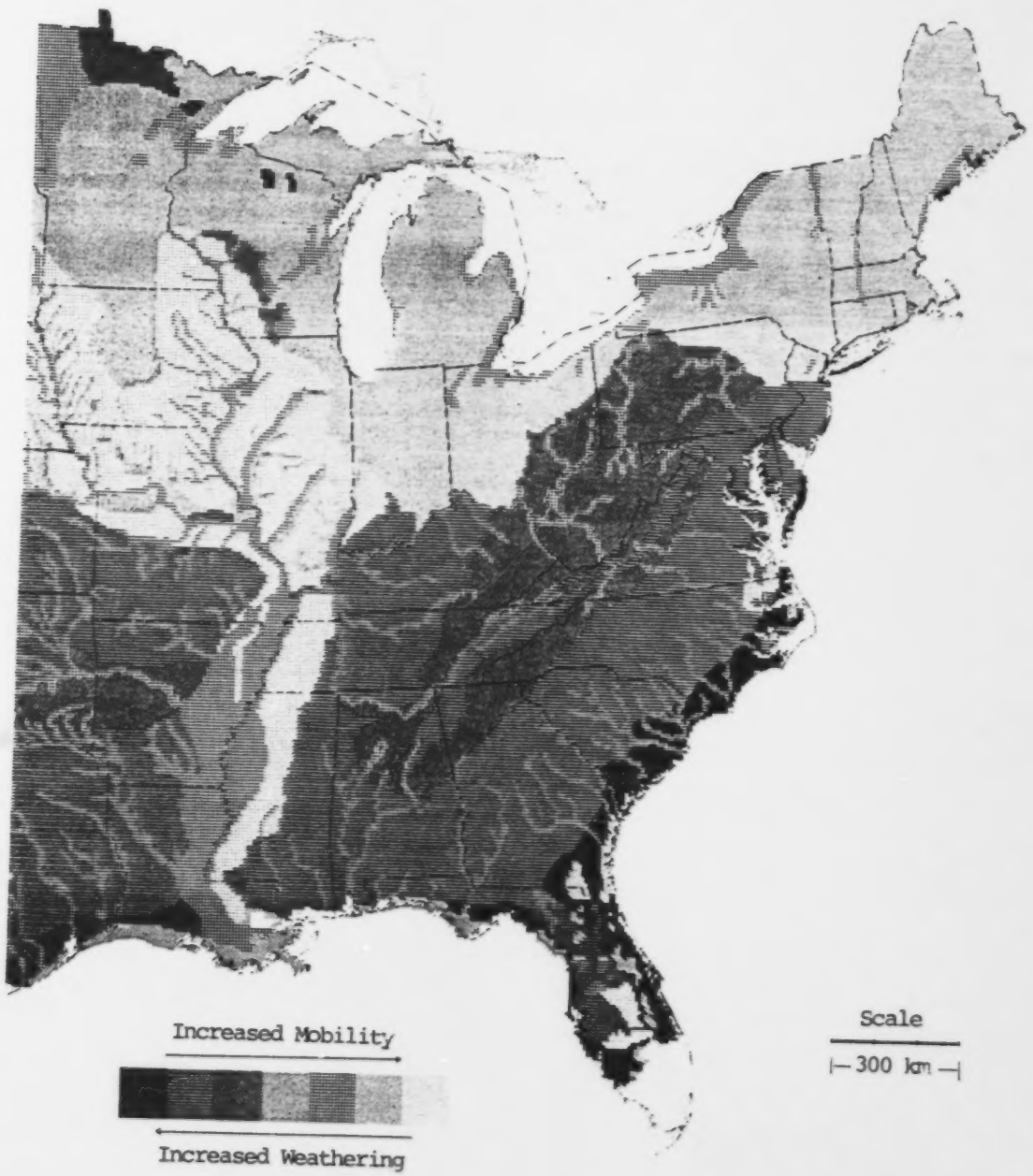


Map 3 (eastern half)

Map 4 (western half)

Surficial Group	Deposits	Percent Area
1 (Gl)	Organic	2
2 (Gl)	Saproletic	27
3 (Gl)	Colluvium	21
4 (Gt)	Glacial	19
5 (Gt)	Lake and Stream	21
6 (Gt)	Shore	1
7 (Gt)	Wind	9

Map 4. Surficial geology of the United States and binary grouping: locally weathered (Gl) and transported (Gt) deposits.



MAP INTEGRATION

This regrouping of the original maps into a few comparable and ecologically related map features facilitates the understanding and interrelating of spatial properties of various land regions. This is a step which must be taken in order to simplify map integration. Vegetation patterns, soil characteristics, land form features and modes of deposit of the surficial material are shown in Maps 1 through 4. Tables 1 through 4 list the grouping features which correspond to these maps.

The graphic display of map features in this study was done interpretively, using darkest shadings for map groups numbered 1 and progressively lighter shadings for higher group numbers. The groups themselves were arranged to reflect gradients of moisture and temperature for vegetation and soils, elevation and relief for land surface form, and weathering and mode of transport for the geology. There is a certain logical correlation linking a group from one map with one or more groups in other maps. For example, colluvium deposits (Table 4), mountainous land forms (Table 3), cool and moist soils (Table 2), and wet or moist forests (Table 1) are ecologically "like" items. These characteristics, found simultaneously at a given location, indicate an ecologically homogeneous area. The regrouping of the original data in this manner simplifies the analysis of map integration by reducing the ecological characteristics to a small number of logically related units. Without this regrouping, map integration would not be meaningful. It may occasionally be advantageous to perform sequential direct overlays of ungrouped maps; first only two maps, then a third map overlayed with the combined map, etc. However, after each overlay, it would be necessary to ignore many detailed features in favor of carrying a few important features, represented by relatively large homogeneous areas to the next overlay. This type of regrouping can be directed by the workers' intuition, their appreciation of spatial patterns, their knowledge of various geographic areas, and the objectives of the work. When approaching the problem in this manner, it is usually not possible to predetermine the total number of classes from an inspection of the data base. It is also difficult to document the procedure in detail and to communicate the rationale followed.

By assigning the number of classes to the map components before performing an overlay, we predetermine the number of land types at different levels of classification hierarchies, beginning with highest levels, where general unifying features are easily detectable, and then progressing to lower levels where the need for consideration of details become evident.

There are 7x5x5x7 = 1225 possible land types if we overlay the four grouped maps constructed according to Tables 1, 2, 3, and 4. This may provide a reasonable level of detail for those areas which require close examination. However, for a national map, this level of detail is excessive and can obscure general patterns. Therefore, in the second step leading to map integration we must again regroup related features in order to reduce the number of land type possibilities. The simplest approach is to form a binary grouping of the items in the four tables. This can be represented symbolically as:

$$V[(1,2),(3,4,5,6,7)] = Vh,Vd$$
$$S[(2,3),(1,4,5)] = Sc,Sw$$
$$F[(1,2,3),(4,5)] = Fp,Fm$$
$$G[(1,2,3),(4,5,6,7)] = Gl,Gt$$

Where V, S, F, and G refer to map names for vegetation, soils, land form, and geology, the numbers refer to the items in the tables and the subscripts (lower case letters) refer to the binary grouping of these items. It can be verified, by referring to the tables, that Vh and Vd refer to moisture conditions, Sw and Sc to temperature conditions, Fp and Fm to slope and relief conditions, and Gl and Gt to the mode of material transport.

An overlay of four maps that are grouped into binary features produces a total of 2x2x2x2 = 16 distinct land types. Each land type is uniquely characterized by one of the 16 combinations such as VhScFpGl, VhScFpGt, ..., VdSwFmGt which describes the spatial correlation of "like" features in vegetation, soils, land surface, and weathered geologic deposits. These land types are

detailed in Table 5. They illustrate the interrelationships of the four ecological features represented by Tables 1, 2, 3, and 4.

The following pattern emerges in Table 5: Given a description which utilizes one to three of the components V, S, F, and G, the ecological description becomes more detailed with the inclusion of each additional component. At the same time, the number of land types indicated by the description, as well as their total areal extent, becomes smaller. For example, 71% of the entire land is in plains and piedmonts, of which 63% has warm soils (-SwFp- = 62.55%).* These numbers are obtained from Table 5 by summing all of those areal percentages designated by Fp and SwFp, respectively. Similarly, the following relationships can be verified: Nearly one-half of the land types in SwFp are covered with humid vegetation (VhSwFp- = 31.81%) and the other half by dry vegetation (VdSwFp- = 30.74%). These lands are further subdivided between those having native weathered geologic deposits and transported deposits. The remaining 10% of land types in Fp are mainly in humid forests with cool soils and transported deposits (VhScFpGt = 7.0%). Land types in Fm can be similarly interrelated with associated characteristics in soils, vegetation and geologic deposits. The least dominant land types are characterized by dry vegetation and cool soils, with total VdSc-- = 1.77%, while the most dominant are those with humid vegetation and warm soils (total VhSw-- = 47.35%). The next most dominant land types have dry vegetation and warm soils, with VdSw-- = 37.06%. The 16 land types are represented in Map 5 by various shades of gray. The darkest shades are in the east, north and the northwest and the lightest in the west and southwest. Relatively large masses of homogeneous land types dominate the east and the central United States. Mosaics of all land types are found in the mountains of the west. The boundaries of various land types appear distinct at this level of resolution. Some details have been omitted to obtain clarity.

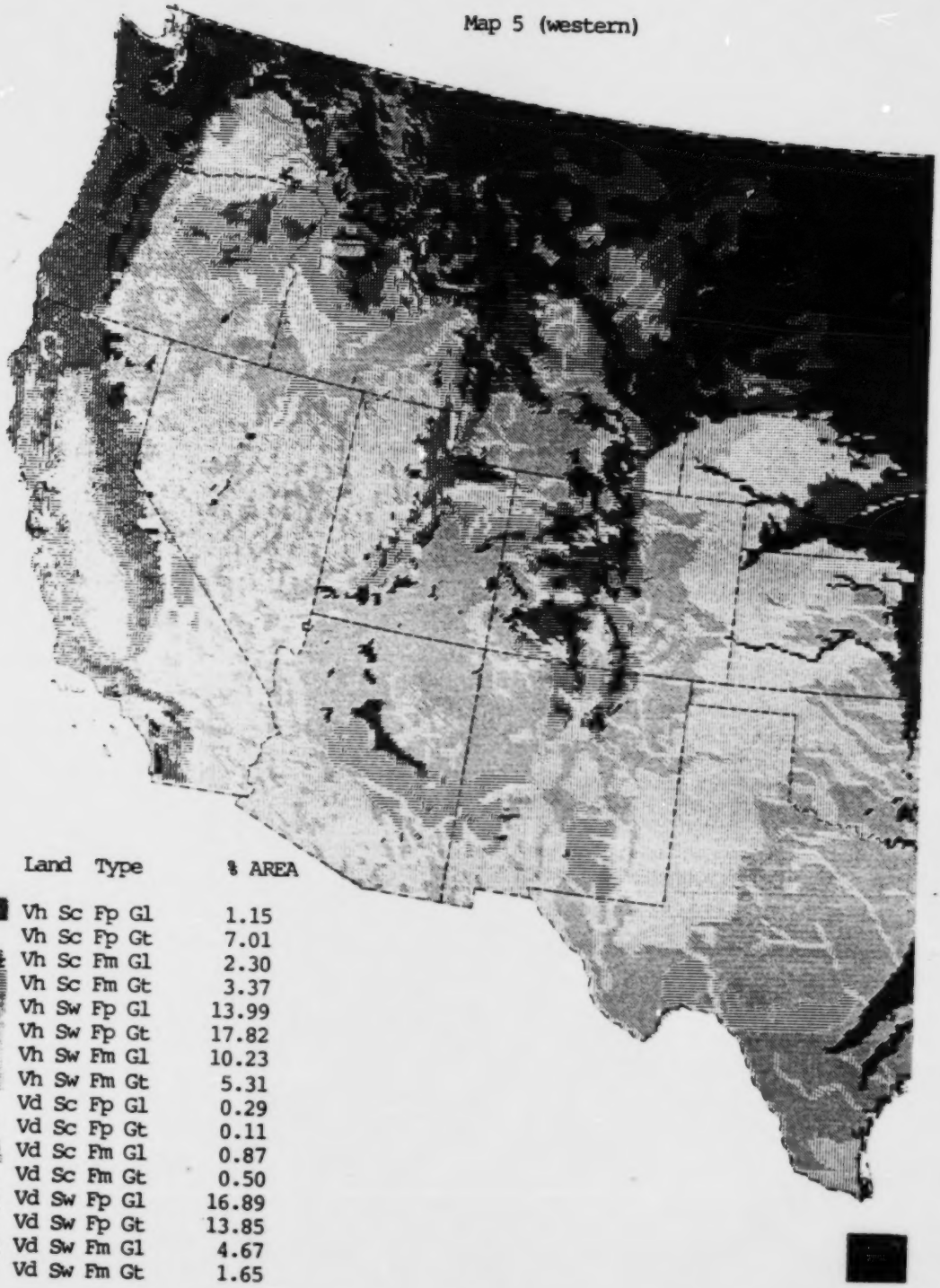
TABLE 5

Land Types of the United States Obtained from the Spatial Correlations of Humid or Dry Vegetation (Vh, Vd), Cool or Warm Soils (Sc, Sw), Plains or Piedmonts (Fp) or Mountainous Lands (Fm), and Locally Weathered (Gl) or Transported (Gt) Geologic Deposits (Map 5)

Land Type	% AREA
Vh Sc Fp Gl	1.15
Vh Sc Fp Gt	7.01
Vh Sc Fm Gl	2.30
Vh Sc Fm Gt	3.37
Vh Sw Fp Gl	13.99
Vh Sw Fp Gt	17.82
Vh Sw Fm Gl	10.23
Vh Sw Fm Gt	5.31
Vd Sc Fp Gl	0.29
Vd Sc Fp Gt	0.11
Vd Sc Fm Gl	0.87
Vd Sc Fm Gt	0.50
Vd Sw Fp Gl	16.89
Vd Sw Fp Gt	13.85
Vd Sw Fm Gl	4.67
Vd Sw Fm Gt	1.65

* Dash (-) indicates components omitted in sequence V, S, F, G.

Map 5 (western)



Land Type	% AREA
Vh Sc Fp Gl	1.15
Vh Sc Fp Gt	7.01
Vh Sc Fm Gl	2.30
Vh Sc Fm Gt	3.37
Vh Sw Fp Gl	13.99
Vh Sw Fp Gt	17.82
Vh Sw Fm Gl	10.23
Vh Sw Fm Gt	5.31
Vd Sc Fp Gl	0.29
Vd Sc Fp Gt	0.11
Vd Sc Fm Gl	0.87
Vd Sc Fm Gt	0.50
Vd Sw Fp Gl	16.89
Vd Sw Fp Gt	13.85
Vd Sw Fm Gl	4.67
Vd Sw Fm Gt	1.65

Map 5. Land types of the United States obtained from the spacial correlations of humid or dry vegetation (Vh, Vd), with cool or warm soils (Sc, Sw), with plains or piedmonts (Fp) or mountainous lands (Fm), and with locally weathered (Gl) or transported (Gt) geologic deposits.

The various shades of gray are roughly correlated with the climate and the biological character of the geographic areas they represent. The darkest shades imply abundance of moisture, moderately cool climate, low to moderate land elevations, geologically native weathered deposits, and dense forests or grasslands. The lightest shades occur in deserts or sparsely vegetated lands. The darkest areas, therefore, coincide with zones of intense geochemical migration and high biological activity. By contrast, the lightly shaded areas represent biologically and geochemically less active environments. While the darkly shaded areas are forests or intensely managed croplands, the light areas are predominantly rangelands. Interpretation of the degree of shading can be instrumental in predicting which land types pose greater waste management problems. The containment of waste within a small area in a site is potentially more difficult in darkly shaded regions. This is because the moisture, temperature, and topographical conditions are more favorable to waste migration and movement in these areas than they are in lightly shaded regions. However, the more intense biological activity and abundance of organic matter in the darker areas indicate a potentially more favorable environment for attenuation of biological effects of toxic waste.

Smaller regions may be examined more closely. Take, as an example, the area south of Lake Erie and containing the State of Ohio. This area is outlined on Map 5. The land area is approximately 320,000 sq. km. There are only two major, one secondary, and two minor land types, as determined by their areal extent. The identification of these land types is shown below using the binary designation.

V	S	F	G	% Area
h	c	p	t	0.40
h	w	p	l	1.7
h	w	p	t	51.1
h	w	m	l	37.7
h	w	m	t	9.1

The details of the binary features can now be examined using the Maps 1, 2, 3, and 4. In the equations below, the map features are indicated on the left and the areal extent of the corresponding vegetation, soil, land types, and geological deposits of various types are given on the right. Only those features which actually occur in the region are shown.

V[1,2] = V[16.9%, 83.1%]
S[1,3,4] = S[8.4%, 0.4%, 91.2%]
F[1,2,3,4,5] = F[42.6%, 9.9%, 0.9%, 17.9%, 28.7%]
G[2,3,4,5] = G[3.0%, 36.3%, 47.9%, 12.8%]

Thus, there are only two types of vegetation, three types of soils, five land forms, and four types of deposits, making a total of 2x3x5x4 = 120 possible land types. However, by regrouping S, F, and G we can readily determine secondary level features in the region. One possible grouping is:

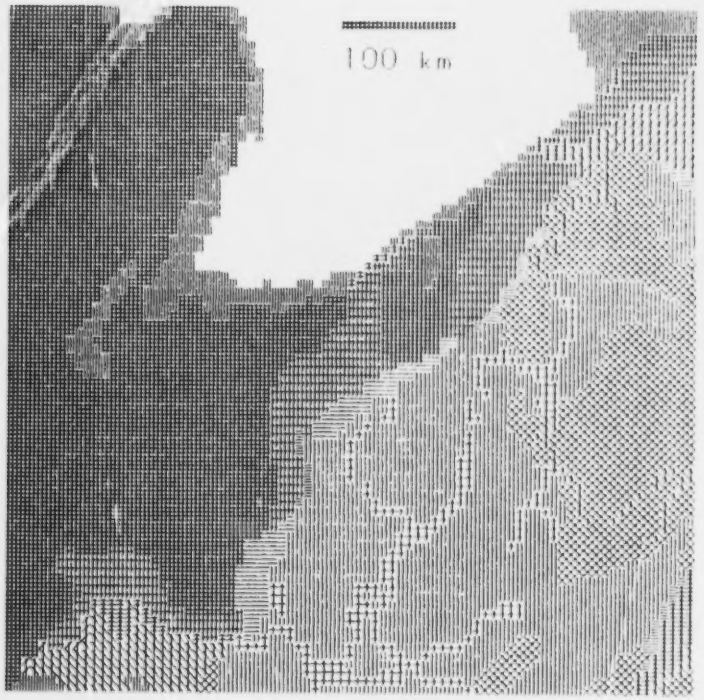
V[1, 2] = V[1,2]	2 classes
S[1,3,4] = S[1,(3,4)]	2 classes
F[1,2,3,4,5] = F[1,(2,3),(4,5)]	3 classes
G[2,3,4,5] = G[(2,3),4,5]	3 classes

This yields a total of 36 possible land types (2x2x3x3). However, some combinations do not occur and a few others have very small areas. The distribution of the remaining land types is listed in Table 6 and illustrated in Map 6.

THE CONNECTIONS WITH THE MICROENVIRONMENT

When a chemical is released from a hazardous waste site it is dispersed by various components of the environment: the air, the water, the soil, and the biota. The dispersal exposes the material to progressively wider scopes of environmental agents which eventually decompose and mineralize the material. But, until this detoxification is complete, there remains the potential for harmful effects as the chemical moves from one element of the environment to another. The movement from soil to water, from water to biota, and from soil

Map 6. Land types south of Lake Erie showing greater detail than in Map 5. V, S, F, and G refer to component maps and numbers refer to corresponding features in each component.



V	S	F	G	Area
1	(3,4)	1	4	1.0
1	(3,4)	(2,3)	4	0.3
1	(3,4)	(4,5)	(2,3)	12.3
1	(3,4)	(4,5)	4	0.5
1	(3,4)	(4,5)	5	2.4
2	1	1	4	5.4
2	1	1	5	1.9
2	(3,4)	1	4	28.9
2	(3,4)	1	5	3.0
2	(3,4)	(2,3)	(2,3)	1.5
2	(3,4)	(2,3)	4	8.2
2	(3,4)	(2,3)	5	0.6
2	(3,4)	(4,5)	(2,3)	26.6
2	(3,4)	(4,5)	4	2.7
2	(3,4)	(4,5)	5	3.4
others				

TABLE 6

Land Types South of Lake Erie Showing Greater Detail than in Map 5. V, S, F, and G Refer to Component Maps and Numbers Refer to Corresponding Features in Each Component (MAP 6)

V	S	F	G	% Area
1	(3,4)	1	4	1.0
1	(3,4)	(2,3)	4	0.3
1	(3,4)	(4,5)	(2,3)	12.3
1	(3,4)	(4,5)	4	0.5
1	(3,4)	(4,5)	5	2.4
2	1	1	4	5.4
2	1	1	5	1.9
2	(3,4)	1	4	28.9
2	(3,4)	1	5	3.0
2	(3,4)	(2,3)	(2,3)	1.5
2	(3,4)	(2,3)	4	8.2
2	(3,4)	(2,3)	5	0.6
2	(3,4)	(4,5)	(2,3)	26.6
2	(3,4)	(4,5)	4	2.7
2	(3,4)	(4,5)	5	3.4

to biota depends upon: (1) the chemical properties of the material; (2) the properties of the biota; and (3) the geochemical properties of the environment.

It is possible to identify the dominant land types (26.6% and 28.9%) with the two dominant land types of the low resolution map. The first one comes mainly from subdividing VhSwFmGl = 37.7% and the second from subdividing VhSwFpGt = 51.1%. It is useful to recognize this type of hierarchical relationship in research and management. It facilitates better use of existing data and planning for new data collection. The description of land types at this level of detail in terms of various map components is more exact, but tedious. It would not be practical to seek a greater subdivision of the land beyond this level using maps on the scale of the National Atlas. Maps of 1:24,000 or higher resolution are preferred for the analysis of site specific problems.

(1) Chemical properties of the material: The chemical properties of significance are: (a) solubility in water; (b) vapor pressure; (c) partition coefficient; and (d) the equilibrium constant of chemical dissociation for acidity and basicity.

(2) Biotic properties: For a chemical to be absorbed by a living organism it must pass through the cell membrane. A number of transport mechanisms are available to accomplish this: Passive molecular diffusion and filtration work downgradient of the absorbed substance and the cell membrane may selectively transport ions or compounds. Absorption is often enhanced by a catalyst introduced by the living cell. Absorption is influenced by the partition coefficient and the equilibrium constant of the chemical substance and by the pH and the reducing or oxidizing character of the natural environment. The oxidized and reduced forms of a given compound may have completely different biological and environmental characteristics.

(3) Geochemical properties of the environment: For a chemical to move from solution to the soil it must be adsorbed by the soil surface so the chemical nature of the weathered soil surface is a primary concern.

(a) There are two major fractions in the soil, the mineral fraction and the organic fraction. The mineral fraction is composed of layer silicates and mineral hydroxides which interact during weathering to give the characteristic layer structure of clay minerals. The layer silicates have large specific surface areas. These accumulate high residual negative charges which are

neutralized by external concentrations of cations. These negative charges are not pH dependent and can be replaced at any pH. Clay surfaces can also assume a negative charge from ionization of hydroxyl hydrogen. This charge increases with the pH of the solution.

The organic fraction of the soil is humus, which is comprised of decomposed plant tissues and microbial residues. The specific surface area of humus is very great. Its cation exchange capacity is far greater than that of mineral fraction and is more strongly dependent on the pH of the environment. Humus adsorbs nonionic organic substances and ionic material, so it has superior characteristics for the limitation of toxic waste migration. Humic substances are very sensitive to oxidation and are formed and destroyed more rapidly than clay.

(b) Almost all chemical and biological soil reactions involve oxidation and reduction reactions. Whether an environment is oxidizing or reducing depends upon the presence or absence of certain minerals and chemical compounds and the action of microbiota in the environment. This inter-relationship between various compartments of the environment has been classified by Perel'man [13, 14]. Table 7 is a generalization of his approach.

TABLE 7
Geochemical Classification of Redox, the pH of the Natural Environment (generalized from Perel'man [13, 14])

		Oxidizing Environments	Reducing Environments
pH	Aqueous migrants	Free oxygen in waters	Biochemically produced CO_2 and CH_4, or H_2S
1 - 4	H^+,SO_4^{--},Fe^{++} Zn^{++},Cu^{++}, H^+,HCO_3^-	Oxidation by sulfuric acid and acid waters Eh < 0.85 V	Gley processes Eh < 0.5 V
4 -6.5	organic acids	---	---
6.5-8.5	Ca^{++},HCO_3^-, Mg^{++} Cl^-,SO_4^{--},Na^+	Oxidation by mineralized waters	Carbonic
8.5-11	Ca^{2+},SO_4^{--}, Na^+,HCO_3^-, OH^-,SiO_2	Oxidation by soda waters Eh > 0.15 V	Soda,Oxysalts Eh < 0.15 V Eh > -0.60 V

Perel'man classified the redox environment by the association of various gases (O_2, CO_2, CH_4, H_2S) with aqueous solutions of ions. Accordingly, an environment can be oxidizing in the presence of free oxygen and oxidizing metals. Or the environment can be reducing in the absence of free oxygen and the presence of CO_2, CH_4, or H_2S. The intensity of oxidation or reduction is dependent on the concentrations of various ions in the aqueous solutions.

Oxidizing environments develop in stages; the pH rising as the Eh of the environment drops. The pH is lowest in the presence of sulfides, free sulfur, or other reducing substances. In these environments microorganisms participate to produce Eh's as high as 0.85 V and pH's as low as 0.2. In contrast, waters containing sodium bicarbonate are weaker oxidizing agents. That is, the Eh is small and the pH is relatively large. Perel'man explains this by reasoning that strong cations (Ca, Mg, Na, K) are more abundant in the earth's crust than are strong anions (Cl, S, P, V). Therefore, more cations go into solution during weathering than do anions. The anion deficiency is compensated for by the

dissociation of water. This dissociation proceeds in such a way that the number of hydroxyl ions increases as long as there is demand for them and the number of hydrogen ions correspondingly decreases. Since natural waters always contain some carbon dioxide, the waters gradually aquire sodium bicarbonate and an alkaline character.

Intensely acid environments are most common in humid and hot or temperate climates, while semi-arid climates generally yield alkaline environments. The strongest reducing environments occur in areas, such as swamps, which experience oxygen depletion due to rapid decomposition of organic matter. Acid reducing environments are found in tundra and permafrost. Neutral reducing environments are characteristic of forest steppes, and desert marshes usually develop alkaline reducing environments. In hot deserts the products of oxidation remain in place as oxidized minerals, while in humid climates they are strongly leached out of the soils. In cold climates the solubility of oxygen in waters increases, but its chemical activity and the activity of microorganisms is generally low. This results in reduced biochemical oxidation of organic matter and explains the accumulation of peat in cold regions.

Examples of these environments can be found anywhere the local conditions are suitable for their formation and maintenance. For example the ionic species, clay minerals, organic content, pH, soil moisture, depth of the groundwater, and biotic community can vary from one point in the environment to another as a result of variations in the landform, geology, and microclimate. The local conditions greatly influence the movement, adsorption, absorbtion, and the degradation of chemicals. However, there are overriding factors that make certain environments dominant over broad geographic regions regardless of local variations.

Application of Map 5 to specific problem types, such as hazardous waste disposal or water quality management, depends on establishing the links between the various effects of chemicals in different biogeoclimatic environments.

DISCUSSION OF MAP UTILITY

Verification of the utility of this map for assessing the toxicity or bioavailability of chemicals in the environment requires data on known chemicals and known organisms. Data obtained from experiments conducted on field sites that generally typify a regional environment are useful for this purpose.

It is outside the scope of this paper to present data for validating any particular use of the map. However, an example will be given, using a limited data set, to show a potential application.

Gunther and Gunther [15] reviewed the adsorption, absorbtion, toxicity, and degradation of parathion in the environment. They reported research findings by many investigators on the effects on parathion of moisture, temperature, pH, minerology, and the organic content of the soil. One finding showed the toxicity of parathion to field crickets in three soils of various moisture contents: fine sandy loam, clay, and muck. Table 8 displays the data. The results show that toxicity increases with soil moisture if there is little or no clay and organic matter in the soil. This trend is reversed in the presence of substantial organic matter and clay content.

The net interaction between the mineral fraction, the organic fraction, and moisture as well as the pH, microbial population, and a host of other unmeasured factors produce the toxicity which is measured in laboratory bioassays of environmental samples. The soils tested are obtained from different environments and to a certain extent represent the original soil environments. Whether or not these same toxicities would be observed in the real environment is difficult to assess without a field verification. It is therefore important to note that the validity, or even the general utility, of the maps cannot be decided with this limited data. In a follow-up study, we intend to make use of laboratory data with various soils, organisms, and chemicals and existing field data to better demonstrate the utility of our approach.

Having stressed the inadequacy of limited data in the above example, we now attempt to explain the correlation of toxicity with land types. The soils

used in these toxicity tests were obtained from sites within those land types listed in Table 8. Since the map's various shades of gray correlate with environmental characteristics, the gray scale is listed in the table alongside the land type. The gray scale is a rough quantitative indicator of the balance between moisture, temperature, mineral availability, land form, etc., that is associated with the intensity of weathering and biological activity. The gray scale numbers are positively correlated with the intensity. The land types and the associated gray scales correlate with the toxicity data in the table. The correlation suggests that low toxicity of parathion is a result of intense adsorption by the soil or degradation by the environment before it affects the target organism. This possibly is an example of the different attenuation capacities of various environments for parathion. A map showing this type of spatial pattern of toxicity of a chemical or a group of chemicals can be extremely useful in environmental management.

TABLE 8
Toxicity of Parathion to Field Cricket [15] Correlated with Land Types of Map 5

Soil	Land Type	Humus (%)	H2O (%)	LD50 ppm
Torrifluvents (Beverly fine sand) WA	V2S2F2G1 Gray Scale = 14	1.44	0.0	12.71
			1.0	7.33
			3.3	1.21
			6.3	0.46
			8.6	0.46
			12.1	0.46
Argiaqualfs (Brookston clay) WI,IL	V1S2F1G2 Gray Scale = 6	15.85	0.0	12.20
			10.0	6.97
			18.0	6.31
			25.0	5.36
			35.0	4.94
			41.0	4.32
Histosols (Muck)	V1S1F1G2 Gray Scale = 2	64.4	0.0	9.10
			40.0	10.97
			70.0	14.16
			100.0	15.92
			130.0	17.82
			162.0	21.11

RECOMMENDATION

There are abundant data in the literature which confirm the toxicity of new or existing chemicals to organisms. The spatial display of data can be made, as in the above example, by correlating chemicals with their toxicities in various land types. The results could be helpful in classifying chemicals with respect to their potential for widespread environmental impact.

Comprehensive sampling of dominant soil environments and testing with selected chemicals and organisms might be a means to classify the attenuation capacity of land types in the United States. Regional maps displaying this information could be quite valuable to researchers and environmental managers.

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